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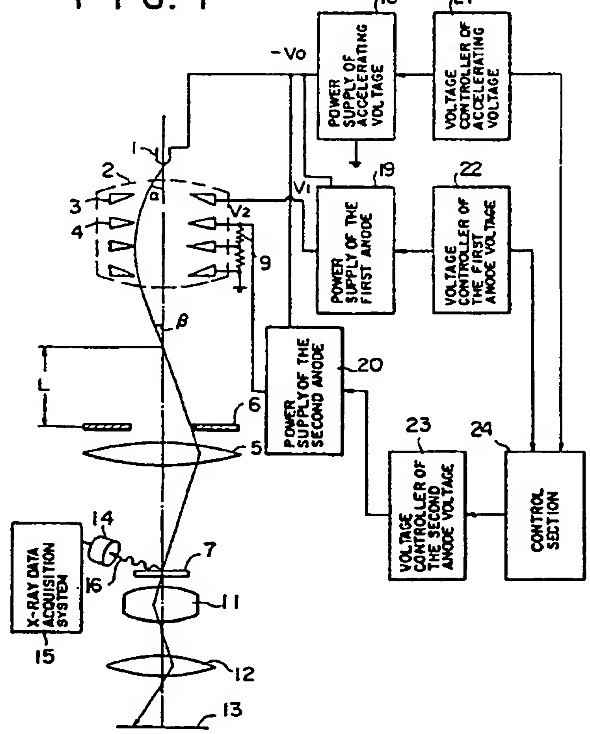
(54) Field emission electron device.

(57) Disclosed is a field emission electron microscope in which a control means (21, 22, 23, 24) is provided to perform control to make an electron beam current fixed against variations in an accelerating voltage or an extracting to thereby make fixed the brightness of an electron beam with which a specimen (7) is illuminated.

F I G. I



EP 0 434 370 A2

FIELD EMISSION ELECTRON DEVICE

The present invention generally relates to a field emission electron microscope, particularly relates to quantitative analysis of the elemental composition of a specimen, and more particularly relates to control of an extracting voltage or an accelerating voltage to be applied to a source.

Fig. 4 shows an example of the conventional configuration of an illumination system of an electron microscope using a field emission source. A field emission current from a field emission source 1 is controlled on the basis of an extracting voltage V_1 applied to a first anode (extracting electrode) 3 in an electrostatic lens 2. A control voltage V_2 for controlling the lens action of the electrostatic lens 2 is applied to a second anode (the first accelerating electrode) 4. A resistor 9 is equally divided so that equal divisional voltages are applied across adjacent electrodes after the second anode 4. A control means for controlling the ratio of the control voltage V_2 for the electrostatic lens 2 to the extracting voltage V_1 to be a fixed value in response to a change of the extracting voltage V_1 is disclosed, for example, in JPA 60-117534. That is, the control voltage V_2 is controlled in response to a change of the extracting voltage V_1. In such a field emission electron microscope, there has been a problem in that when a specimen is illuminated with an electron beam and the characteristic X-rays are detected to thereby perform quantitative analysis of the elemental composition of the specimen, the beam so fluctuates that it has been impossible to perform accurate analysis.

It is therefore an object of the present invention to provide a field emission electron microscope in which even when the extracting voltage V_1 or the accelerating voltage V_0 to be applied to the source is adjusted in any way, the beam current limited by an aperture becomes always fixed so that a specimen can be illuminated with an electron beam with fixed brightness.

An aperture 6 for limiting an electron beam current is disposed between the electrostatic lens 2 and the principal plane of a condenser lens 5 for focusing an image of the electrostatic lens 2 onto a surface of a specimen 7 or a predetermined point in the vicinity of the specimen. In this case, let the distance between the aperture 6 and the focal position of the electrostatic lens 2 be L, and let the exit half-angle of the electrostatic lens 2 limited by the aperture 6 having a diameter of 2γ be β. Then, the relation : $2\gamma = 2L\beta$ is established. Further, let the exit half-angle of the source corresponding to the exit half-angle β of the electrostatic lens 2 be α, then the exit half-angle of the source limited by the aperture 6 having a diameter of $2L\beta$ becomes α. Therefore, let the angular intensity (an emission current per unit solid angle) of the field emission source 1 be ω, then the beam current at the aperture 6 becomes $\pi\alpha^2\omega$. The angular intensity ω varies in accordance with the extracting voltage V_1. The extracting voltage V_1 for obtaining a desired value of the angular intensity ω varies depending on the emission source. Further, if the emission source is heated so as to clean the surface thereof, the radius of curvature of the source varies so that the relation between ω and V_1 also varies as time elapses. Thus, in order to maintain the angular intensity ω in a desired value, it is necessary to change the extracting voltage V_1. Since the lens action of the electrostatic lens 2 varies as the V_1 varies, in order to fix the beam current limited by the aperture 6, it is necessary to adjust the electrostatic lens action on the basis of the control voltage V_2.

In order to attain the foregoing object, according to the present invention, there is provided an applied voltage control means for changing the control voltage V_2 applied to the accelerating electrodes after the second anode (the first accelerating electrode) 4 in response to a change of the extracting voltage V_1 applied to the first anode (the extracting electrode) 3 or the accelerating voltage V_0 applied to the source 1 so that the ratio of $L\beta/\alpha$ is fixed.

The beam current at the aperture 6 having a diameter of $2\gamma = 2L\beta$ becomes $\pi\alpha^2\omega$ as described above. If $L\beta/\alpha$ is fixed, the exit half-angle α of the source I limited by the aperture 6 having a diameter of $2L\beta$ becomes fixed. Therefore, if the relation among V_2, V_1 and V_0 are properly controlled so that ω is kept to have a fixed value and the condition of $L\beta/\alpha = K$ (fixed value) is satisfied, the beam current at the aperture 6 is always fixed so that a specimen can be always illuminated with an electron beam with fixed brightness.

Referring to Fig. 2, description will be made as to the specific operation for controlling the control voltage V_2. In the drawing, respective curved solid lines (a) and (b) represent relational curved lines between V_2 and V_1 in the case where V_0 = 200 kV and V_0 = 100 kV. In either case, the condition of $L\beta/\alpha = K_1$ (a certain fixed value) is satisfied while the field emission current is kept to be a predetermined value (30 μA in an embodiment described later). Those relational curved lines are obtained by calculating the electron orbit of the electrostatic lens or obtained experimentally as will be described later. That is, if the relation among V_2, V_1 and V_0 is on the curved solid line (a) or (b), such conditions that the field emission current is kept to be a fixed value and $L\beta/\alpha = K_1$ (= fixed value) are satisfied. This means that in any of the combinations of

(V_2 = A, V_1 = 4 kV, and V_0 = 200 kV),
(V_2 = B, V_1 = 6 kV, and V_0 = 200 kV) and
(V_2 = C, V_1 = 4 kV, and V_0 = 100 kV),

the field emission current is kept to be a fixed value and the $L\beta/\alpha$ is also kept to be a fixed value, and therefore the beam current at the aperture is always fixed for the foregoing reason. Accordingly, if the relation among V_2, V_1 and V_0 shown by the curved solid lines (a) and (b) is stored in a control section for generating a control command so that V_2 is controlled so as to come on the curved solid line (a) or (b) in response to a change of V_1 or V_0, the beam current at the aperture is fixed. As a result, the brightness of an electron beam with which a specimen is illuminated can be controlled so as to be fixed.

In the drawings

Figs. 1 and 3 are diagrams showing the configurations of embodiments of the present invention ;

Fig. 2 is a diagram for explaining the control operation of the present invention, the diagram showing relation curved lines among V_2, V_1 and V_0 stored or operated in the control section ; and

Fig. 4 is a diagram showing the configuration of a conventional example.

Referring to Fig. 1 an embodiment of the present invention will be described hereunder.

In the configuration of Fig. 1, an X-ray detection means is additionally provided in a transmission electron microscope having a field emission source mounted thereon. An electron beam emitted from a field emission source 1 is accelerated by an electrostatic lens 2 so as to have a desired accelerating voltage, and the condition of illumination onto a specimen is adjusted by a condenser lens 5.

The electron beam transmitted through the specimen is focused by an objective lens 11 and a projection lens 12 so that an image of the transmission electron microscope is formed on a fluorescent screen 13. Further, X-rays 16 generated by a mutual action with the beam in the specimen are detected by an X-ray detector 14, and a treated X-ray energy spectrum is displayed in an X-ray data acquisition system 15. The X-ray energy depends on the kind of elements constituting a specimen. Accordingly, if attention is paid onto the X-ray count value of the energy corresponding to a certain element, quantitative analysis of the element can be performed. Since the X-ray count value depends on an electron beam current, it is necessary that the electron beam current is always fixed so as to perform quantitative analysis of the element. Description will be made hereunder as to means for controlling an electron beam current.

An aperture 6 for limiting a beam current is disposed on an optical axis between the electrostatic lens 2 and a principal plane of the condenser lens 5 for focusing an image of the electrostatic lens 2 onto a specimen 7 or a predetermined position in the specimen. In a control section 24, the values of the control voltage V_2 which satisfy the condition that the value of the $L\beta/\alpha$ is fixed with respect to the extracting voltage V_1 and the accelerating voltage V_0 are stored as data or given as a functional expression $V_2 = f(V_0, V_1)$. Although the relation among V_2, V_0 and V_1 is obtained by calculating the electron orbit if the electrostatic lens 2, such a value of V_2 which makes the beam current on a specimen fixed with respect to a combination of V_0 and V_1 may be experimentally obtained by measuring the beam current on the specimen. The respective values of V_2 which satisfy the relation $L\beta/\alpha = K_1$, for example, with respect to the combinations (V_0 = 100 kV, 200 kV ; and V_1 = 4-7 kV) are stored in the control section 24 as the curved lines (a) and (b) shown in Fig. 2 or given as certain functions.

First, for example, in order to make the source accelerating voltage V_0 be 200 kV, the source accelerating voltage V_0 is applied from a power supply 18 for supplying the accelerating voltage through a controller 12 for controlling the accelerating voltage. Next, the extracting voltage V_1 is applied from a power supply 19 for supplying the first anode voltage through a controller 22 for controlling the first anode voltage till a field emission current flowing in a first anode 3 has reached, for example, 30 μA. Here, assuming that the field emission current has reached a desired value of 30 μA at V_1 = 4 kV, the field emission current is fixed to this value. The control section 24 reads the value (220 kV) of V_0 and the value (4 kV) of V_1 from the power supplies 21 and 22 respectively, calculates the value V_2 = A which satisfies the relation $L\beta/\alpha = K_1$, and generates a command signal so that V_2 = A is supplied as the control voltage V_2 from a power supply 20 for supplying the second anode voltage through a controller 23 for controlling the second anode voltage. If the value of V_0 is 6 kV for flowing the field emission current of the same value of 30 μA, the control section 24 calculates the value V_2 = B which satisfies the relation $L\beta/\alpha = K_1$, and generates a command signal so that V_2 = B is supplied as the control voltage V_2. By the foregoing operation, the beam current limited by the aperture 6 is automatically made to have the same value in both the cases where V_1 = 4 kV and V_2 = 6 kV. In the control system described above, the control voltage V_2 is controlled so as to vary in response to the extracting voltage V_1.

Alternatively, the control voltage V_2 may be controlled in response to the source accelerating voltage V_0 so that the operational condition of the illumination system is kept fixed. For example, when the value of the source accelerating voltage V_0 varied into 100 kV with extracting voltage V_1 fixed to 4 kV, the control section 24 generates a command signal so as to make the control voltage V_2 = C. As a result, the condition $L\beta/\alpha = K_1$ is satisfied and the beam current at the aperture 6 is fixed.

Further, in Fig. 2, the control voltage V_2 corresponding to the value $L\beta/\alpha = K_2$ is illustrated as shown by a curved broken line. Thus, the control voltage V_2 can be set corresponding to each of a plurality of values of $L\beta/\alpha = K_2$, so that the beam current limited

by the aperture 6 can be also controlled without changing the field emission current.

Although the drawings have been illustrated as to the case where the electrostatic lens focuses an image on the real image side thereof, in the case where the electrostatic lens forms an image on the virtual image side, the beam current limited by the aperture 6 cna be kept fixed in the configuration shown in Fig. 3. That is, the aperture 6 for limiting the electron beam current is disposed between the electrostatic lens 2 and the principal plane of the condenser lens 5 in the succeeding stage of the electrostatic lens 2, and the control voltage V_2 is controlled in accordance with the extracting voltage V_1 or the source accelerating voltage V_0 so as to make fixed the product $L\beta/\alpha$ obtained by multiplying the distance L between the aperture and the focusing position of the electrostatic lens 2 on the virtual image side by the angle magnification β/α of the electrostatic lens 2 to thereby keep the beam current limited by the aperture fixed.

Although description has been made as to a transmission electron microscope in the foregoing embodiments, the beam current control means according to the present invention can be applied also to a scanning electron microscope, a scanning transmission electron microscope, an electron beam lithography system, and the like in which a field emission source is mounted, a deflection coil is disposed between the source and a specimen, and an electron beam deflection means is provided.

As described above, according to the present invention, the aperture for limiting an electron beam current is disposed between the electrostatic lens and the principal plane of the condenser lens in the succeeding stage of the electrostatic lens, and the control voltage V_2 is controlled in response to a change of the extracting voltage V_1 or the source accelerating voltage V_0 so as to make fixed the product $L\beta/\alpha$ obtained by multiplying the distance L between the aperture and the focusing position of the electrostatic lens by the angle magnification β/α of the electrostatic lens. Accordingly, the beam current limited by the aperture is always fixed and a specimen can be always illuminated with an electron beam with fixed brightness even if V_1 or V_2 varies in any way.

Claims

1. A field emission electron device comprising :
   a field emission source (1) ;
   an electronic optical means (1, 2, 5, 6, 9, 18, 19, 20) for illuminating a specimen with an electron beam emitted from said field emission source ; and
   means (21, 22, 23, 24) for fixing an electron beam current on said specimen.

2. A field emission electron device according to Claim 1, in which said electronic optical means includes :
   an electrostatic lens (2) having an extracting electrode for causing said field emission source to field-emit an electron beam therefrom, and having an accelerating electrode (4) of at least two stages for accelerating said electron beam ;
   a focusing lens (5) for focusing an image of said electrostatic lens onto a specimen or a predetermined position in the vicinity of said specimen ; and
   an aperture (6) disposed between said electrostatic lens and said focusing lens for limiting a beam current.

3. A field emission electron device according to Claim 1 or 2, in which said electron beam current fixing means includes a voltage control means (21) for applying a control voltage to said accelerating electrode so as to make the value of $L\beta/\alpha$ fixed, where L, α and β represent a distance between a focal position of said electrostatic lens and an aperture surface, an exit half-angle of said source, and an exit half-angle of said electrostatic lens, respectively.

4. A method of controlling a field emission electron beam, in which an electron beam from a field emission source (1) is transmitted through an electronic optical system (2, 5, 6) and the electron beam is made fixed on a specimen (7).

5. A method of controlling a field emission electron beam according to Claim 4, in which an accelerating electrode (4) is controlled in response to a variation of a voltage applied to an extracting electrode (4) so as to make the value of $L\beta/\alpha$ substantially fixed, where L, α and β represent a distance between a focal position of said electrostatic lens and an aperture surface, an exit half-angle of said source, and an exit half-angle of said electrostatic lens, respectively.

6. A method of controlling a field emission electron beam according to Claim 4, in which an accelerating electrode (4) is controlled in response to a variation of an accelerating voltage applied to said field emission source so as to make the value of $L\beta/\alpha$ substantially fixed, where L, α and β represent a distance between a focal position of said electrostatic lens and an aperture surface, an exit half-angle of said source, and an exit half-angle of said electrostatic lens, respectively.

7. A field emission electron microscope which is constituted by additionally providing a detector

(14) in a field emission electron device as defined in Claim 1.

F I G. 1

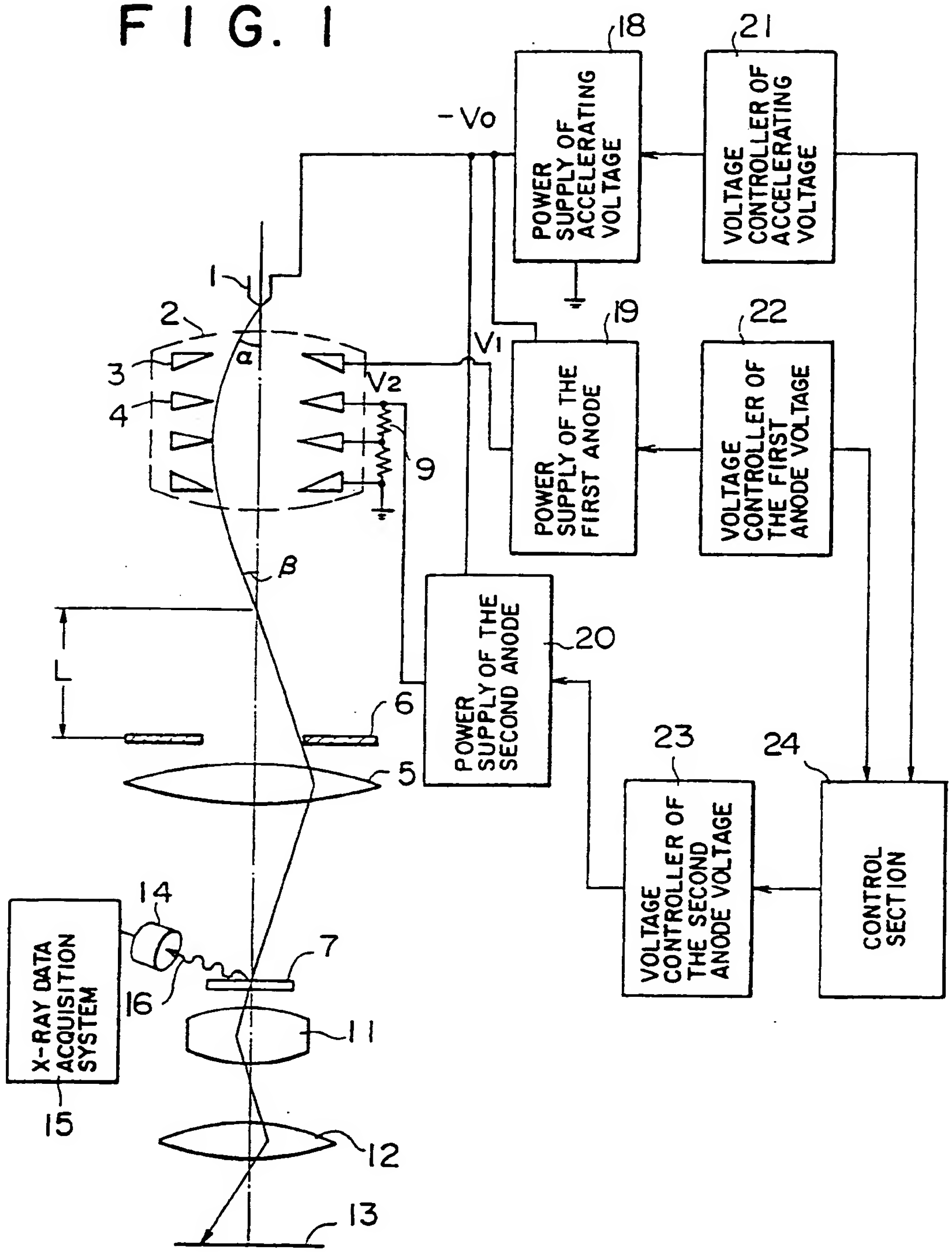

POWER SUPPLY OF ACCELERATING VOLTAGE
VOLTAGE CONTROLLER OF ACCELERATING VOLTAGE
POWER SUPPLY OF THE FIRST ANODE
VOLTAGE CONTROLLER OF THE FIRST ANODE VOLTAGE
POWER SUPPLY OF THE SECOND ANODE
VOLTAGE CONTROLLER OF THE SECOND ANODE VOLTAGE
CONTROL SECTION
X-RAY DATA ACQUISITION SYSTEM
-Vo
V1
V2
α
β
L
1
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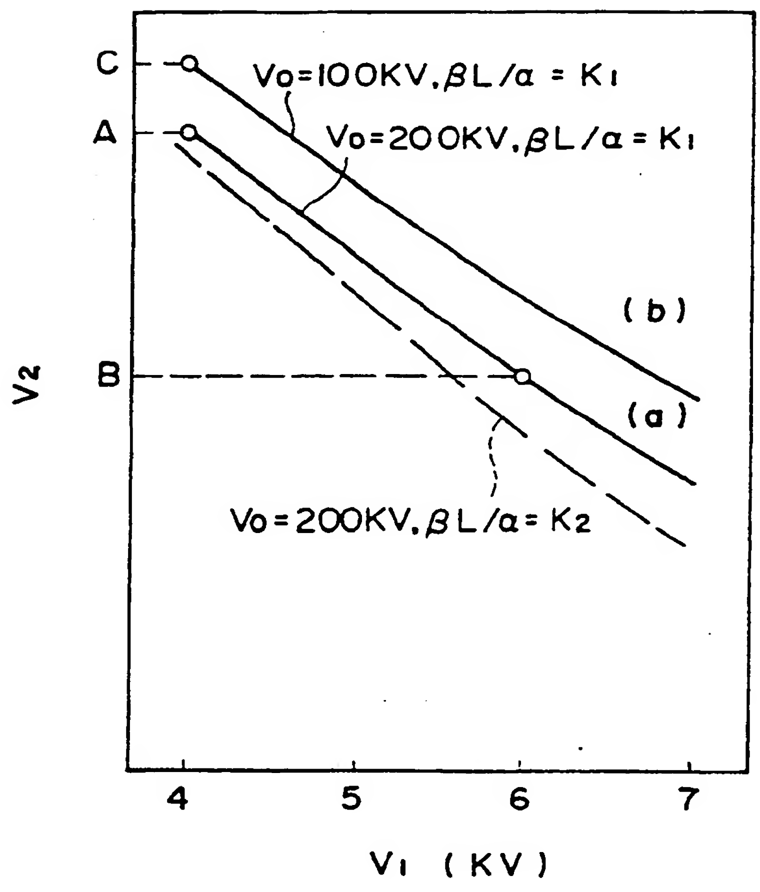
FIG. 2


C
A
B
V2
Vo=100KV, βL/α = K1
Vo=200KV, βL/α = K1
Vo=200KV, βL/α = K2
(b)
(a)
4
5
6
7
V1 (KV)

F I G. 3

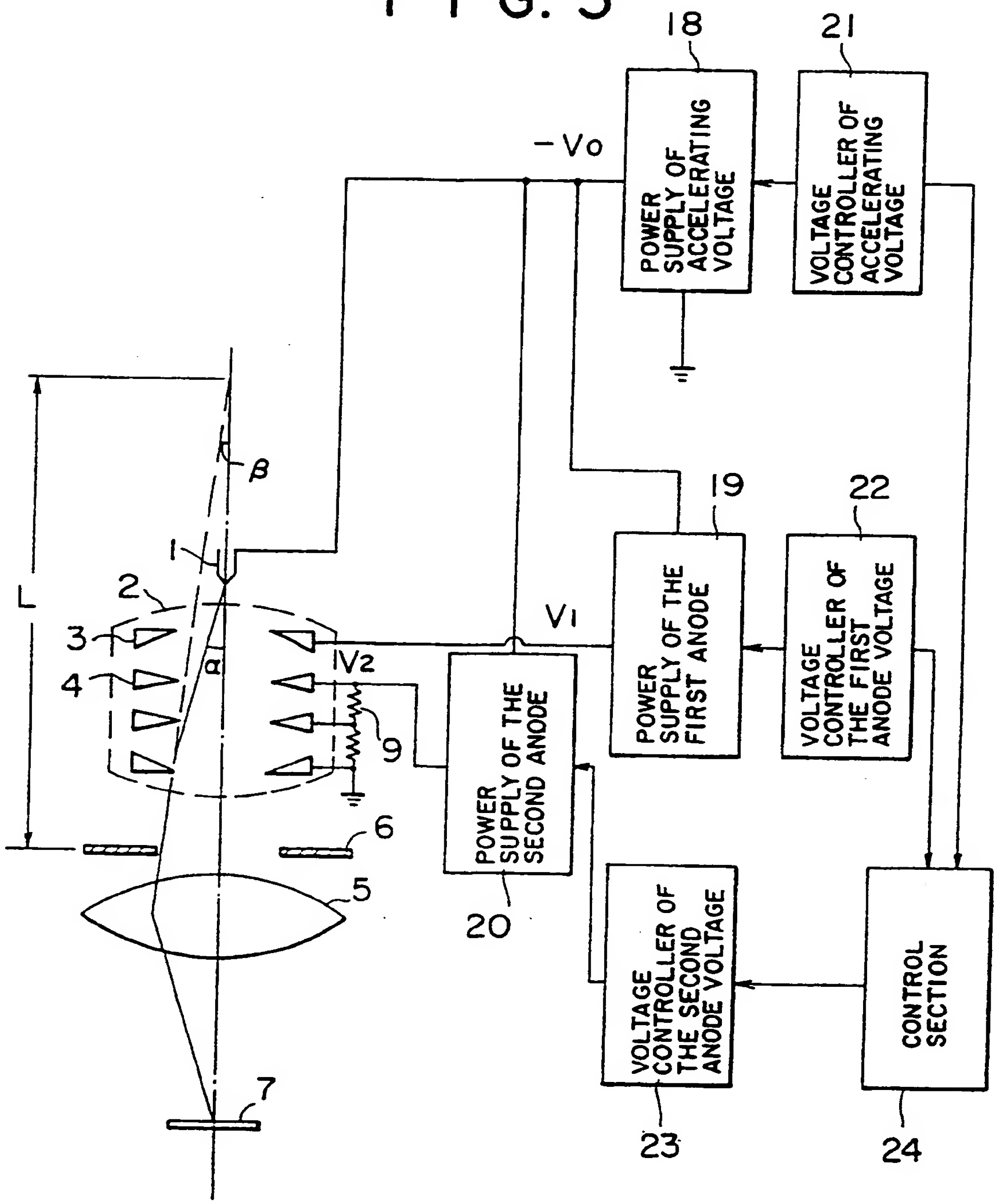
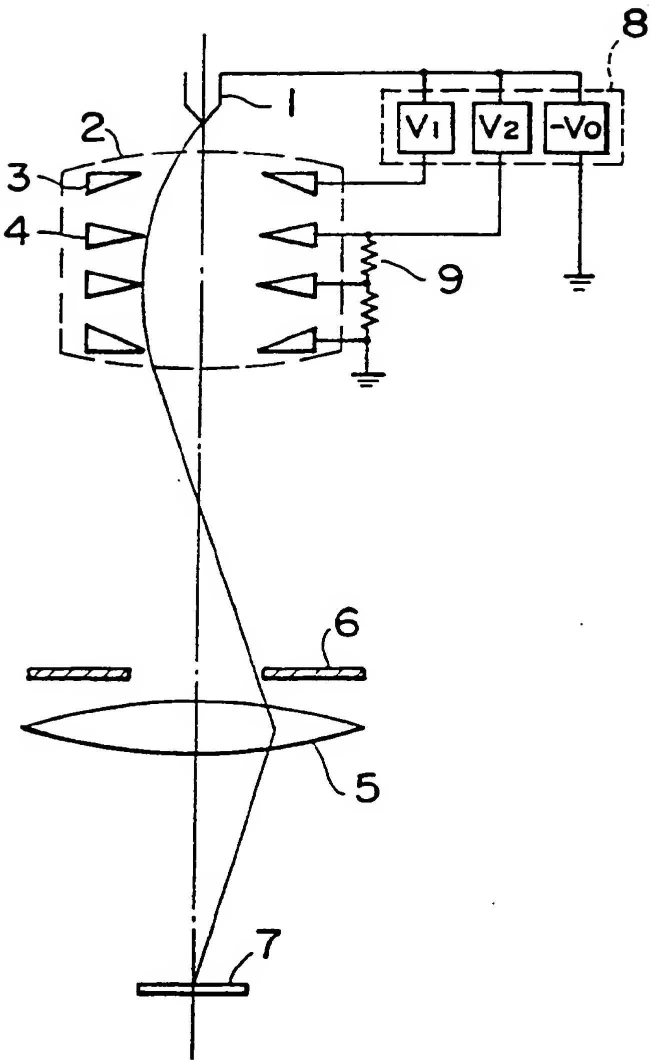

18
21
POWER SUPPLY OF ACCELERATING VOLTAGE
VOLTAGE CONTROLLER OF ACCELERATING VOLTAGE
−Vo
β
L
1
2
3
4
α
V1
V2
9
6
5
7
19
22
POWER SUPPLY OF THE FIRST ANODE
VOLTAGE CONTROLLER OF THE FIRST ANODE VOLTAGE
POWER SUPPLY OF THE SECOND ANODE
20
VOLTAGE CONTROLLER OF THE SECOND ANODE VOLTAGE
23
CONTROL SECTION
24

FIG. 4

PRIOR ART



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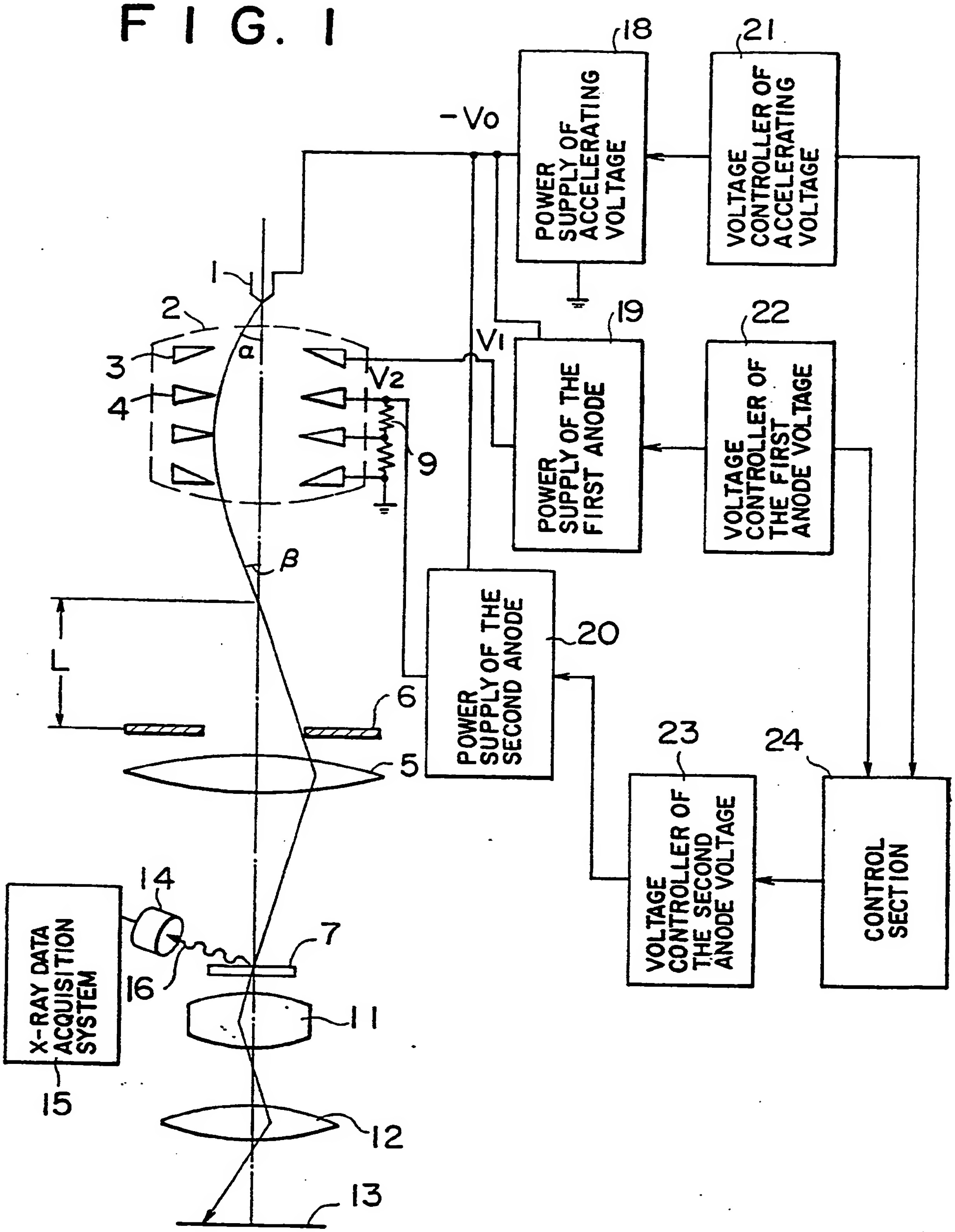
F I G. 1



18
21
-Vo
POWER SUPPLY OF ACCELERATING VOLTAGE
VOLTAGE CONTROLLER OF ACCELERATING VOLTAGE
1
2
3
4
α
V1
V2
9
19
22
POWER SUPPLY OF THE FIRST ANODE
VOLTAGE CONTROLLER OF THE FIRST ANODE VOLTAGE
β
L
20
POWER SUPPLY OF THE SECOND ANODE
6
5
23
24
VOLTAGE CONTROLLER OF THE SECOND ANODE VOLTAGE
CONTROL SECTION
14
7
16
X-RAY DATA ACQUISITION SYSTEM
15
11
12
13

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 31 3855

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-3786305 (KOMODA ET AL.) * abstract; figures * * column 2, lines 41 - 62 *	1, 4	H01J37/073 H01J37/24
Y		2, 7	
D,Y	US-A-4642461 (ENDO ET AL.) * abstract; figures * * column 3, lines 44 - 68 *	2	
Y	PATENT ABSTRACTS OF JAPAN vol. 8, no. 264 (E-282)(1701) 04 December 1984, & JP-A-59 134539 (HITACHI SEISAKUSHO K.K.) 02 August 1984, * the whole document *	7	
X	INTERNATIONAL JOURNAL OF ELECTRONICS. vol. 38, no. 4, 1975, LONDON GB pages 531 - 540; J R A Cleaver: "Stabilization of the electron probe current in the scanning electron microscope with a field emission cathode" * abstract; figure 1 *	1, 4	TECHNICAL FIELDS SEARCHED (Int. Cl.5) H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	07 JUNE 1991	COLVIN G.G.

CATEGORY OF CITED DOCUMENTS

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Y : particularly relevant if combined with another document of the same category
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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